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In Situ Expedient Test Methods to Determine Geotechnical Properties of Dredged Materials

PURPOSE: This technical note describes several test methods useful for determining selected geotechnical properties of dredged materials. The described tests may be performed at the dredging operations site (in situ testing conducted on the dredge platform) but are preferably conducted in a field laboratory at the site or an offsite laboratory. The described tests are conducted on dredged materials sampled from the site and do not include descriptions of the prerequisite sampling methods or procedures. In situ site investigation techniques such as the cone penetration, standard penetration, remote vane shear, and borehole tests are also not addressed in this technical note.

BACKGROUND: Geotechnical characterization of soil and rock dredged materials is necessary for planning, engineering design, and management of dredging operations, and a systematic method of describing the various properties of soil and rock for dredging purposes is needed (Permanent International Association of Navigation Congresses (PIANC) 1984). Dredging research conducted by the U.S. Army Engineer Research and Development Center (ERDC) has increased the knowledge database regarding dredged material properties and is helping to develop systematic methods for characterizing geotechnical properties of dredged materials (Spigolon 1995).

Laboratory tests to determine geotechnical properties of soil and rock have been standardized by organizations such as the American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO), but no standards address test methods specific to dredged material soil and rock characterization. The variability in properties and performance behavior of dredged material soil and rock often leaves the selection of characterization test methods open to interpretation. The end purpose will guide the interpretation process. For example, soil classification requirements for the end purpose of determining dredgeability may differ from those needed for input into sediment fate models.

Regardless of the purpose for obtaining geotechnical properties of dredged material, the following laboratory tests generally will provide basic information about the dredged material soil properties:

- Soil classification and description.
- Grain size analysis and distribution.
- Water content.
- Specific gravity of solid particles.
- Bulk or in situ density.
- Shear strength.
- Stress-strain behavior characteristics.

Performing standardized laboratory soil testing is often time-consuming and relatively costly, depending on the degree of confidence and precision requirements. Faster and more economical test procedures are available, although they are less accurate than the standardized tests. Laboratory testing for accurate results is essential, but simpler tests that can give faster results are also valuable when characterizing dredged materials (PIANC 1984). The following test methods address expedient procedures and simpler equipment for characterizing dredged materials.

TEST METHODS: The test methods listed below will provide the geotechnical parameters most likely needed for dredged material soil characterization. A brief description of the more accurate and standardized laboratory test method precedes descriptions of expedited or nonstandardized test methods. All tests listed below are performed on dredged material samples, and typically those samples are contained in a 5-gal bucket or in a gravity core barrel.

Soil Classification and Description. Classifying the dredged material by soil type provides the most basic geotechnical information. One of two standardized approaches is generally followed for classifying the soil material, depending on the information needed. ASTM Standards D2487 and D2488 (ASTM 2000a, b) both address material classification tests and procedures.

ASTM D2487 provides definitions for gravel, sand, silt, and clay and describes classification for engineering purposes using the Unified Soil Classification System (USCS). It is a comprehensive method and requires performance of the Atterberg Limit tests (D4318 (ASTM 2000c)), sieve analysis (D422 (ASTM 1963)), and water content by mass (D2216 (ASTM 1998)). These tests are not expedient. The oven-drying requirement of 12 to 16 hr by the ASTM D2216 water content method is the most time consuming process. A quicker alternative to the ASTM D2216 water content method is the D4643 (ASTM 2000d) microprocessor-controlled microwave method. The soil samples are placed in a microwave oven and dried to a constant mass in a matter of minutes instead of conventional oven drying which takes hours.

The second method for soil classification, D2488 (ASTM 2000b), is the visual-manual method. Atterberg Limit tests and water content tests are not required. Sieve analysis and visual inspection methods are required. Examining the soil following this procedure will provide descriptive information including particle shape, angularity, color, odor, moisture state, consistency, cementation, structure, HCl reaction, and hardness. Such examination enables soil identification for preliminary soil classification based on the USCS.

Another method for soil classification does not reference the USCS but provides agricultural soil definitions (U.S. Department of Agriculture (USDA) 1967). Although the information provided by the USDA classification system is limited from an engineering viewpoint, it can be used advantageously for qualitative assessments during site investigations (U.S. Department of the Interior 1985).

Grain Size Analysis and Distribution. Grain size analysis is an integral part of soil classification in that it enables determination of the exact composition and distribution of particles sizes. Grain size analysis consists of separating size classes by sieving for coarse-grained particles and by using the hydrometer for fine-grained particles. The standard particle analysis tests are performed using a weight basis instead of a volume basis. Designation D422 (ASTM 1963) covers the sieve

and hydrometer procedures required for particle analysis, and references options for dry sample preparation or wet sample preparation (ASTM 1985, 2000e).

Particle size distribution consists of quantifying the size classes by percentages based on weight from the graphical results of the grain size analysis (ASTM 1963). The weight percentages are calculated for those particles passing (or finer than) designated sieve sizes and hydrometer results and displayed as gravel percentage; coarse, medium, and fine sand percentages; silt percentage; and clay percentage.

Although standardized, quantitative, and accurate grain size analysis and distribution methods may be utilized in the field, these methods are not considered to provide expeditious in situ results, mainly because of the laboratory procedures and equipment specified. Alternatives that may provide for more rapid in situ test results are described in D2488 (ASTM 2000b). Three procedures are suggested for estimating the percentages of gravel, sand, and fines in a soil sample:

- The jar method, in which a soil-water mixture is shaken and allowed to settle, enables estimation of the relative proportions of each size class. Correlations to laboratory particle analysis should be performed.
- The visual method, in which the relative percentages of size classes are visually estimated, is based on volume fractions.
- The wash test, in which the relative percentages of sand and fines are determined, is based on comparing prewash and postwash sample weights.

In situ and expedient size class distribution estimates may be made using several manufactured test kits that are based on variations of the three procedures listed above. Figure 1 shows a device used for determining the sand content by volume. This device is typically utilized in the petroleum industry for determining the sand content by volume of bentonitic slurries, and is fully described in D4381 (ASTM 1993).

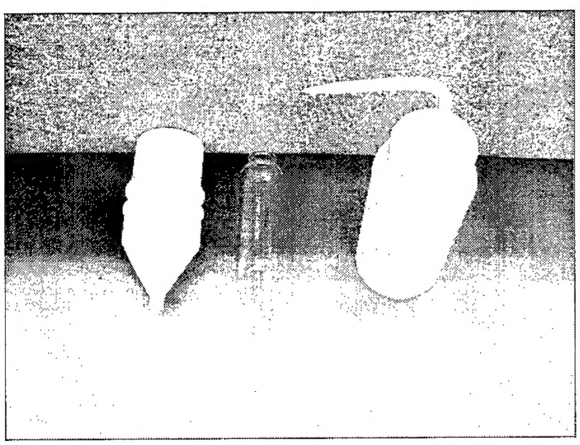

Figure 1. Apparatus used by the petroleum industry for determining sand content by volume

No sample weights are required, and a small amount of soil slurry sample is placed in the glass tube, filled with site water, and shaken. The mixture is washed through a #200 sieve (75-micron-size openings), and the coarser material is then washed back into the glass tube. Tube gradations indicate the relative percentage of material coarser than the #200 sieve. This device and method may be appropriate for in situ dredged material evaluation for those materials containing up to about 20 percent sand. Laboratory testing was conducted to evaluate its performance using dredged material samples, and it was shown to provide a rapid estimate of the sand percentage with minimal effort and equipment.

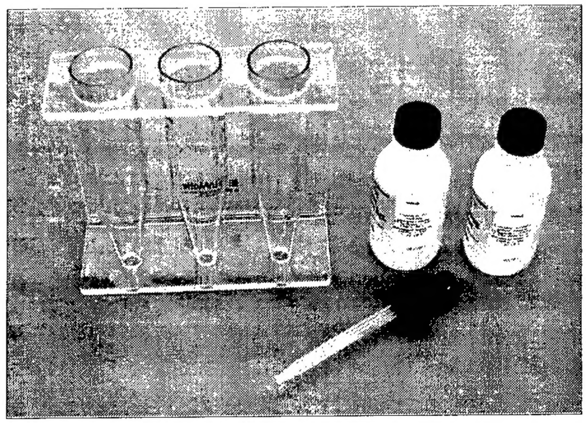

Figure 2. Test kit apparatus for determining sand, silt, and clay percentages by volume

Figure 2 shows an in situ method useful for estimating the relative percentages of sand, silt, and clay using chemical reagents. This method is generally used for agricultural applications. No sample weights are required, and a small amount of soil is placed in one tube, shaken, and allowed to settle within a given time. At a prescribed time, the supernatant is placed into the second tube, reagent is added to aid flocculation and allowed to settle within a given time. The supernatant from the second tube is then poured into the third tube and allowed to settle. The relative percentages of sand, silt, and clay are determined after observing the amount of material in each tube that settles out of the suspension. Laboratory testing was conducted to evaluate the performance of this test method utilizing dredged materials, and it was found to be appropriate for such a purpose. Varying results were observed for a material having a large amount of fines, so its use may be appropriate only to obtain a very general qualitative estimate of particle distribution.

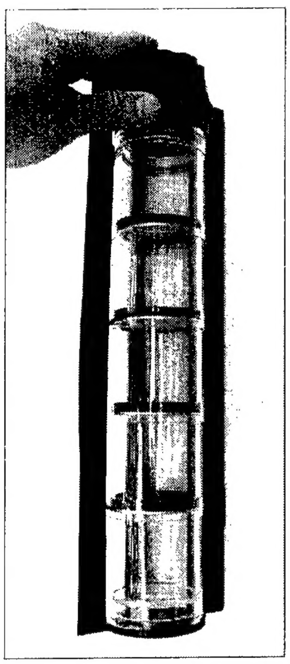

Figure 3. Apparatus for visually estimating particle size distribution

Figure 3 shows another method for rapidly obtaining particle size distributions. This method utilizes standard sieves for separating particle sizes, similar to the D422 (ASTM 1963) equipment and procedure. Instead of determining the distribution by weight, this device allows for the option of visually determining the particle size range distribution by relative volume. The sample is required to be dry, which may limit the effectiveness of this method for field evaluation of dredged materials, but no sample weighing is required. A small portion of dried soil is placed in the upper end of the tube containing standard sieve sizes. The tube is shaken until the particles segregate by size class, and the relative size class distribution is visually observed via gradation marks on the tube supports. Laboratory testing of dredged material was not conducted with this device because of the sample preparation required. However, for dredged materials that have been dried and disaggregated, this apparatus will allow rapid estimation of the particle size distribution by visual observation of the soil fraction retained in each canister.

Several manual methods for determining particle size distribution of fluvial (stream and riverbed) sediments are listed in D4822 (ASTM 1988). The methods include those whose results are in percent of mass (weight), percent by volume, and percent by number of particles. Particle counting methods yield results in percent by number of particles, and nonmicroscopic optical particle counting methods yield results in both percent by number of particles and percent by volume. Particle counting methods are suggested for cohesionless soils only. The methods that have the widest range of applicability for soil types normally encountered in dredged materials are the dry sieve and hydrometer methods referenced heretofore.

Research by Muri, Holm, and Hamre (2001) has shown that traditional hydrometer tests for determining the grain size distribution of silt and clay may some day be replaced by modern laser diffraction (particle counting) techniques. A laser diffraction instrument was utilized at a field site in Norway, and it provided excellent comparability with the traditional hydrometer test. Using such a particle counting technique will likely reduce potential handling error and time duration inherent to hydrometer analysis, and it should be evaluated for applicability to dredged material characterization.

Water Content. There are no standardized methods for rapid and accurate in situ determination of soil water content by mass other than the microwave oven method D4643 (ASTM 2000d). Rapid field drying methods are available, but they are not standardized, and they have not been evaluated using dredged material. The traditional oven drying method requires several hours as previously discussed. Figure 4 illustrates the accuracy of the microwave oven method compared to the traditional oven method.

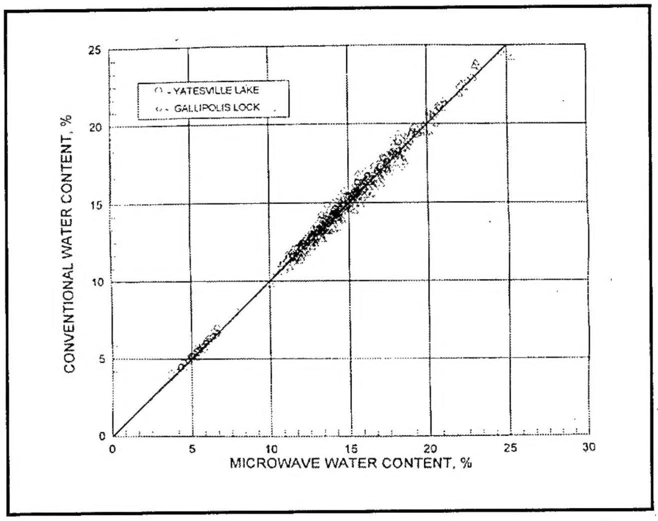

Figure 4. Water content by mass determination using microwave oven versus conventional oven (after Gilbert 1988)

Rapid qualitative assessment methods are available for determining soil water content by measurements other than mass, but their applications to dredged material with its typical high water content (by mass) have not been assessed for the purpose of this technical note. Utilizing a description of water content by any measurement other than mass (or weight) will lead to erroneous phase relationships when calculating certain other soil parameters such as specific gravity, density, and void ratio.

Since many dredged materials are in a saltwater environment, methods to determine salinity content are often needed. One expedient method that is referenced in D4542 (ASTM 1995a) uses a simple hand-held refractometer to determine pore water salinity.

Marine soils in certain parts of the world are composed of calcareous minerals instead of the more common silicate minerals. Characterizing dredged materials obtained from those environs includes a determination of the calcium carbonate content of the soil minerals. An expedient in situ method which approximates the calcium carbonate content is described as method D4373 (ASTM 1996a), in which a dried portion of soil is placed in a rapid carbonate analyzer and dosed with a chemical reagent. An enclosed pressure gage reads the carbonate percentage.

Bulk Density. Bulk density (or saturated wet density) is not a standardized measurement for soils, but it is standardized for concrete aggregate materials. It is a relatively simple measurement to obtain and is very useful for dredged material characterization. Knowing the sample weight and volume, the bulk density may be calculated as weight per volume. A rapid in situ assessment method is to fill a bucket of known volume with dredged material, weigh it on a weight scale, and subtract

the bucket weight. To obtain an accurate density measurement, the bucket volume must be known or determined, and the weight scale must be accurate and be properly positioned.

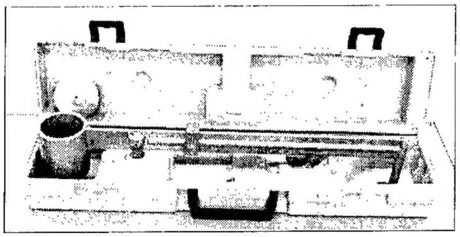

Figure 5. Bulk density measurement apparatus for rapid in situ dredged material characterization

An alternate rapid measurement method may also be achieved with the drilling industry's mud balance device (Figure 5). The apparatus consists of a manufactured device of known weight and internal volume. The steps of adding soil to the open cup, covering it with the cap, balancing the beam, and reading the beam scale allow for a rapid assessment of the soil density or specific gravity with reasonable resolution. The test method and apparatus are standardized and described in D4380 (ASTM 1984) for use with bentonitic slurries. The device and test method have been evaluated using dredged material slurries with varying water contents and the results indicate a high degree of utility for rapid dredged material characterization.

Specific Gravity. The two standardized methods for measuring specific gravity of soil solids are the D854 (ASTM 2000f) and the D5550 (ASTM 2000g). These methods use the water pycnometer or the gas pycnometer and require special equipment and materials such as an oven, balance scales, and de-aired water.

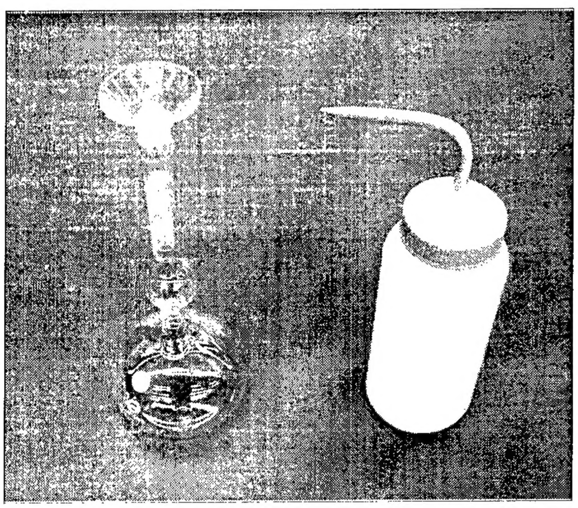

Figure 6. Specific gravity measurement with a Le Chatelier flask

One alternate method that allows rapid determination of soil solids specific gravity was developed for hydraulic cement and is the standard method C188 (ASTM 1995b). It requires a Le Chatelier glass flask with marked gradations (Figure 6). The flask is filled to a designated gradation with kerosene fluid, and a preweighed amount of cement is placed in the flask. The subsequent height rise of kerosene is noted to calculate the cement density. The cement density divided by the density of water yields the specific gravity. The method was evaluated using dredged materials (both air-dried and at natural water content), and the specific gravity of the soil particles was determined by substituting site water for kerosene, since cement hydration prevention was not an issue. To calculate the soil density, the soil weight was divided by the displaced water volume in the flask. Knowing the site water density, the specific gravity of the soil particles was calculated. This method is useful for rapidly determining the soil specific gravity, but special care must be taken to properly place and mix the introduced soil into the flask.

Stress-strain Behavior Characteristics. Adequate investigation of dredged material behavior when subjected to stress requires laboratory testing of engineering properties including shear strength, compressibility, permeability, and soil consistency at various water contents.

Shear strength: Shear strength of dredged material soil is an important parameter for modeling soil behavior under applied stress loading, especially when predicting mound stability and confined aquatic placement site stability. Traditional laboratory testing includes triaxial testing for cohesive soils and direct shear testing for cohesionless soils, and the traditional tests are generally standardized. Shear testing of dredged materials is typically not performed using traditional equipment, since the materials may have very low confining pressures and may be too weak to support their own weight. For very soft cohesive soils (silts and clays) and very loose cohesionless soils (sands) typically encountered in dredged materials, the traditional testing methods may require special procedures when setting up the specimen and equipment. Traditional laboratory strength testing methods are neither expedient nor suited for in situ tests.

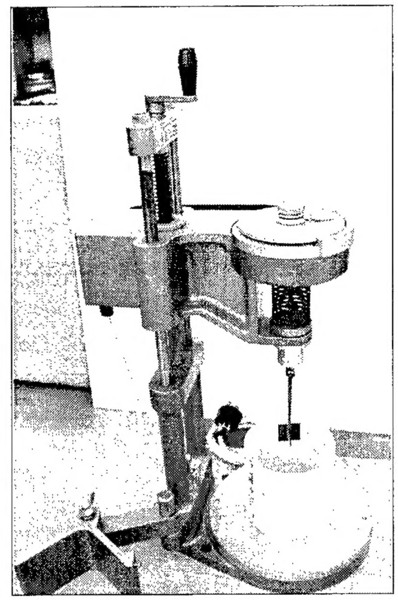

Figure 7. D4648 miniature vane shear test apparatus for saturated fine-grained clayey soil

Expedient in situ test methods are available and include a standard test method as well as a nonstandard test method. A standard test method is the D4648 miniature vane shear test for saturated fine-grained clayey soil (ASTM 1994), and a nonstandard method is the hand-held vane shear test. Figure 7 shows the D4648 test apparatus, and Figure 8 shows a hand-held tester.

Both methods consist of inserting a vane into the soil sample and rotating it at a constant rate to determine the torque required to cause a cylindrical surface to be sheared by the vane. The torque is converted to a unit shearing resistance (shear strength) of the cylindrical surface area. The miniature vane shear apparatus (Figure 7) is motorized and requires a 110-volt electrical source. Of the two devices, the hand-held unit is the simplest and easiest to use. Both units were evaluated by the author for dredged material applicability, and the motorized unit yielded the most consistent and repeatable results. The size of the vanes must be properly matched to the shear strength range, and for the typical very soft soils with shear strengths less than about 100 lb/sq ft (5 kPa), the vane diameters need to be wider than usual. Tests with various vane diameter widths are ongoing.

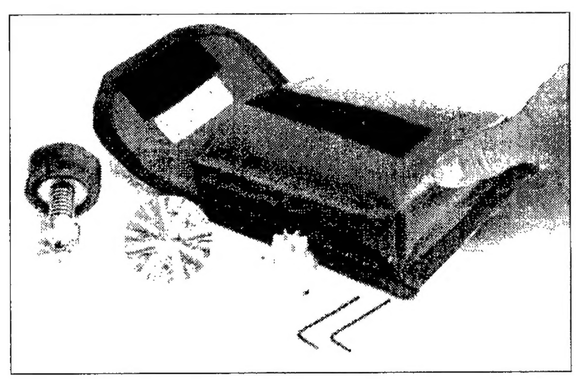

Figure 8. Hand-held pocket vane shear tester

Compressibility: Because of its typical very low shear strength and high water content, dredged material soil is difficult to test for compressibility (stress-strain relationship) and consolidation (compressibility-time relationship) characteristics. One-dimensional (1-D) consolidation devices and test methods (ASTM 1996b) are available for this purpose, and a self-weight consolidometer apparatus and method have been developed specifically for evaluating dredged material consolidation (U.S. Army Engineer (USACE) 1987), but the self-weight apparatus and method have not been standardized by any testing organizations. Presently, no expedient in situ test method is available for accurately determining the compressibility or consolidation characteristics of dredged material.

Permeability: Knowing the dredged material's capacity to absorb and release internal water pressure during compression is crucial for determining the transport and fate mechanisms of contaminants often found in dredged materials. Knowledge of the permeability (or hydraulic conductivity) is also critical for evaluating geotechnical stability in constructed features such as confined aquatic disposal cells. Laboratory testing for permeability is typically accomplished during the 1-D consolidation test or is conducted using the falling head test for cohesive materials or the constant head test for cohesionless materials. These standardized tests are not addressed herein because of their inapplicability as expedient in situ test methods.

Presently, no suitable in situ test method readily applicable to dredged materials is available for accurately determining the soil permeability as a function of water content or void ratio. Expedient test methods used with other materials such as asphalt and concrete may be available, and agricultural soil permeameters may also be evaluated for dredged material applicability. These possibly expedient methods have yet to be evaluated for their applicability to dredged material characterization.

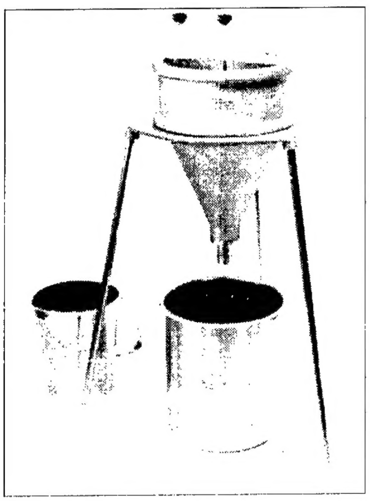

Figure 9. Flow cone set for measuring flowability

Consistency tests: Dredged material may be found in a state of consistency ranging from fluid-like suspended sediment to solid soil. Since suspended sediment behaves more as a viscous fluid, viscosity and flowability testing methods and procedures are appropriate. Those test methods and procedures are borrowed from other materials testing regimes as necessary, since there are no soils testing standards that address a fluid or slurry state. For example, the grouting industry tests flowability (timed flowrate) of hydraulic grout in the field using the ASTM C939 (ASTM 1997) flow cone set as shown in Figure 9. Its usage may be applicable to dredged material characterization for soils with very high water contents.

For dredged material soils with water contents closer to the soil's liquid limit, another test method to measure consistency and flowability has been evaluated. The slump test, similar to the ASTM C143 concrete slump test (ASTM 2000h), has provided good correlation between slump, shear strength, and water content properties of dredged materials. The slump test for soil materials was originally conceived and practiced for usage in rapid assessment of yield strengths in waste mine ore tailings (University of Melbourne 1996). Figure 10 illustrates the slump test method.

Figures 11 and 12 illustrate the correlations between slump test, water content, and undrained vane shear strengths for dredged material sampled from the Pascagoula, MS, harbor.

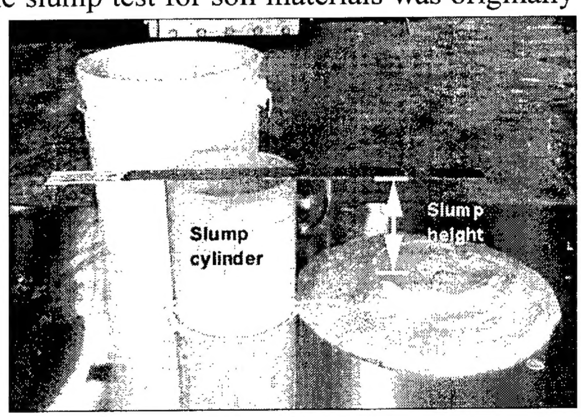

Figure 10. Dredged material slump test

As a general rule, if the water content of a materials increases, its shear strength decreases as its slump increases. The slump test provides a method to correlate these properties using a relatively simple technique. The material is placed in a cylindrical container (the slump cylinder), tapped lightly to release entrapped air pockets, and leveled off at the cylinder top. The cylinder is then slowly lifted as the material flows in an outward fashion until it reaches an equilibrium flow pattern. When the material stops flowing outwardly, the slump height (distance between the cylinder top and the top surface of the material) is measured. If calibration curves for slump height, water content, and shear strength are available from laboratory testing of a given material, the slump test is a useful monitoring technique for rapidly assessing water content and shear strength parameters. Slump testing of various dredged materials and calibrations to water content and shear strength is another ongoing activity of the DOER work unit for evaluating geotechnical properties of dredged materials.

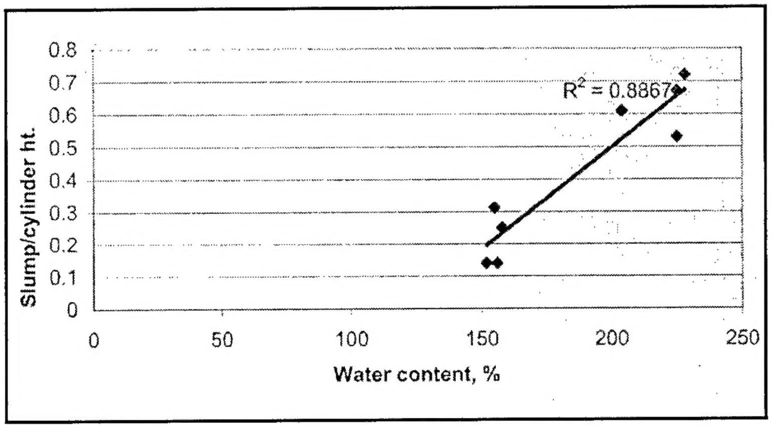

Figure 11. Pascagoula harbor dredged material slump test correlation to water content, 4-in.-diam slump cylinders

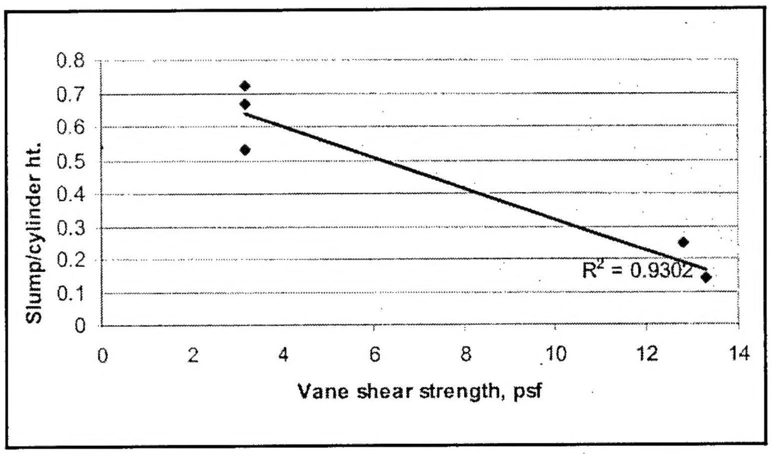

Figure 12. Pascagoula harbor dredged material slump test correlation to undrained vane shear strength, 4-in.-diam slump cylinders

SUMMARY AND CONCLUSIONS: Dredged material characterization methods span a wide range of engineering properties and behavior, and often the material properties are difficult to interpret because of their wide variation. For example, dredged materials often have extremely high water contents and extremely low shear strengths when compared to typical nonaquatic soils. In addition to the problem of characterizing dredged material peculiarities, inherent in the characterization challenge is the lack of standardized testing procedures addressing geotechnical testing of dredged material.

This technical note addresses laboratory-testing procedures for the most commonly sought-after geotechnical parameters applicable to dredged material characterization. In particular, those nonstandardized methods which potentially enable rapid in situ testing are noted. The nonstandardized methods are generally simpler and faster, but they are not as accurate as the laboratory standard methods (where available) and should not be construed as substitutes for the standard methods.

Several in situ, expedient, and simple testing methods are presented for determining soil classification, particle size analysis, water content, salinity content, carbonate content, specific gravity of soil solids, bulk density, shear strength, and stress-strain behavior characteristics. Other nonstandard methods may be available that are not discussed in this technical note.

Ongoing research in dredged material geotechnical properties is being conducted and includes utilization of both standardized and nonstandard testing methods. Better understanding of the geotechnical material behavior will enable development of a suite of recommended methods for dredged material characterization.

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> Lee, L. T. (2001). "In situ expedient test methods to determine geotechnical properties of dredged materials," *DOER Technical Notes Collection* (ERDC TN-DOER-N12), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer/*

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